Analysis of Substation Data

A report by Working Group I-19 to the Relaying Practices Subcommittee, of the Power System Relaying Committee, Power Engineering Society of the IEEE.

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ABSTRACT

From the time of the installation of the first protective device, protection engineers have been forced to attempt to solve the complex problems involved in the determination of operational correctness. As protective relaying systems became more complex special monitoring devices were created to give the engineers the data necessary to both analyze and solve these complex problems.
This paper will attempt to explain in easy to understand terms how an engineer should approach this problem resolution. The data provided from both new technology devices and older models will be addressed.

INTRODUCTION

In the past the utility engineer often struggled with the fact that little data was available when attempting to analyze problems within power systems. They also did not have enough information to predict or ascertain the level of maintenance needed or when it would be required for the major equipment located within their substations. As new and higher levels of technologies have made their way into the utility environment, these same engineers are now suffering from data overload. They have more data than can be processed and assimilated in the time available. Thus important knowledge concerning the status of substation equipment is just lying stagnant and not being used to the betterment of either the personnel or the equipment.
This "data overload" not only has impact on each piece of equipment, or substation, but also at the system level. The data might be coming from sensors in breakers or transformers or some could even be available in other monitors already located in the substation (i.e. fault recorders, event recorders, RTU's and microprocessor based relays).
An overall flow chart of the analysis process has been developed to assist younger personnel in the analysis of power system events (both simple and complex). Although, these flow-charts are not a definitive work, it is meant to be a tool or aid in the development of new electric system fault analysis tools. The first part of this paper will address a complete description and analysis of the flow chart. This will be followed by several real world examples analyzed using the process described.

THE ANALYSIS PROCESS

WHAT IS AN EVENT? An event is a relay or switching operation or an inadvertent operation caused by changes in power system parameters measured at the substation.
Figure 1 shows the decision making process for the first evaluation of the event and its assessment. The first decision to be made is "Did Something Happen? This information can come via SCADA systems, Fault Recording systems, or possibly human observation. If the answer is no then nothing needs to be done. One must remember that if data is recorded something did happen on the system, it might not be readily apparent and it might not be of significance, but something did happen! If the significance of what happened can not be determined, the data available should to be archived for possible later analysis.
Should the answer be yes, something did happen. Then the analysis process should continue by attempting to define what happened. The engineer at this point should determine if the data is part of a cycle of events (i.e. part of a reclosing cycle or the initial operation). Notes should be made at all stages of the analysis process as to where data is coming from, the time accuracy of the data and places where more data might be acquired.
Should this event initiate a reclose then data should be obtained on each of the subsequent operations and included in one report of findings.

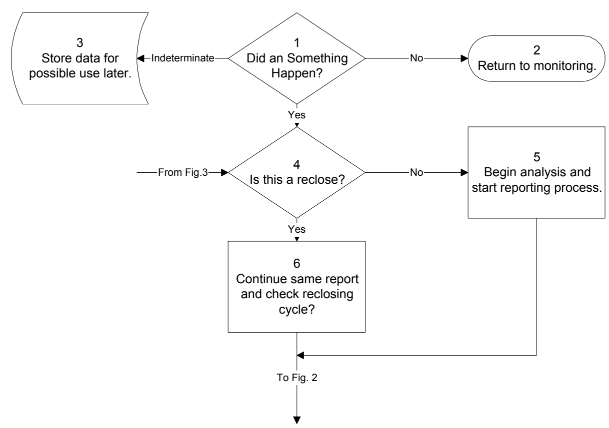


Fig. 1

COLLECT DATA

At this point a good understanding of the types of devices in use on the system to be investigated is important (i.e. what kinds of data is available?). As stated earlier the first data available may be the data used in the determination that an event occurred.
It would do well to note at this time that data in most cases comes to the analyst little pieces at a time. During the time lags the analyst continually creates scenarios about the power system that would match the data available. At any given moment the analyst might determine the correctness or incorrectness of the event and thus search for data to verify or nullify the given premise.
However, to attempt to cover all bases and insure a good understanding of where data is available, it must be assumed that all available data will be collected.

SCADA SYSTEMS

There are many different types of data that needs to be accessed. SCADA systems provide indications of what equipment operated and what equipment is in or out of service. Basically there are two types of SCADA systems in use today.

The older systems have a time associated with each change, however, that time may not be very accurate or precise. A good understanding of the time tagging process for the SCADA system is use can be critical in the use of this data.

New SCADA systems can provide sequence of events type data accurate to a millisecond. This data can be used just like sequence of event recorder data, which will be discussed later.

At this time a discussion on time and time synchronization follows:

There are two methods that can be used to synchronize data from different sources. The first is to sync the clocks of all devices so they all use the same time. This can be done by using a GPS clock at each location as an input to the device.

The second and oldest method is to determine simultaneous data points on the separate devices and attempt to reconstruct the timing sequence.

It is very desirable that all times within the system be synced to within one millisecond, as the operation of the protective devices can only be accurately determined with at least this resolution.

SEQUENCE OF EVENTS RECORDERS

In more complex substations a Sequence of Events Recorder (SER) is often used to insure the recording of status and status change of different devices within the substation. Typically, change of status is recorded and time tagged to a one-millisecond time.

Earlier SER's simply recorded the sequence of operations and did not time tag. These recorders are still of value, however, correlating events between devices is very difficult.

An SER would record things such as:

- Breaker Position
- Breaker Alarms
- Transformer Alarms
- Lockout relay position

For a more complete analysis the following should be considered for monitoring:

- Relay trip outputs
- Trip coil current presence
- Close coil current presence
- Pilot channel status and alarms

FAULT RECORDERS

The basic fault recorder records analog voltage and currents not on a long-term rms basis, but as instantaneous measurements of the energy flows. Early models were hard copy oscilloscopes. These progressed to the stage of very rapid start units with a various amount of pre-event values available.

Presently, digital fault recorders (DFR) have settable pre and post fault times and complex initiating sensors. A fault recorder may also allow the recording of digital events and can take the place of or provide a supplement to SER's.

Data from DFR's can provide a true picture of the operation and response of the electric system during times of events. The data collected within a DFR can normally provide the following:

Pre, During, and Post Fault voltages and currents on any monitored quantity. These are not just magnitudes, but also wave shape and frequency components.

One-millisecond resolution digital events normally displayed graphically along with the analog waveforms.

The value of having these waveforms is highlighted when a system misoperates and a distortion in the waves is found to coincide with the event.

However, due to channel limitations within a given substation, it may be necessary to use records from multiple substation recorders to have all of the phases required.

RELAYS AND RELAYING SYSTEMS

Historically, relays have provided very little amounts of data. The electro-mechanical targets of older relays do provide an indication of what system or what protective element initiated the event.

Newer relays and relaying systems provide much more valuable data. The modern relays can provide fault magnitude, fault duration, targeting data, fault type information, fault location, SER type data, and fault recorder waveforms. These systems do not provide the high sample rates available in a digital fault recorder, but do provide a recording of what the relay saw. This recording can be either at the terminals, after the filtering, or both.

Today's relaying components provide much more information than was available in the past and are very useful, especially if the relays within a station are time synced. The data becomes even more beneficial if the different substations are time synced.

OTHER DATA SOURCES

There are many other avenues to pursue when analyzing power system events. These do not have to be investigated normally, but in extreme cases they can prove very valuable. Recording meters can provide some information. These may be of the pen recorder type or the newer digital. On-site investigation may be necessary. As built drawings may be need to determine exactly how the system was installed. Protective relay settings compared to what was applied to the relay may be of benefit. Finally, human observation can provide answers or clues to sequence of failure or initiating event.

So, as the problems become more complex, begin "beating the bushes" for all the data that can be found.

DATA TO INFORMATION TRANSFORMATION

There are various calculations and determinations that need to be made in order to provide the necessary information needed for analysis.

1. If possible combine all digital type events from the differing pieces of equipment into one time tagged substation sequence of events.

2. Determine Pre-Fault, During Fault, and Post-Fault voltage and current magnitudes, phase angles and power (MW, MV).
3. Determine fault type. (One to ground, one to two, three phase, evolving, etc.)
4. Determine the duration of the fault.
5. If possible determine fault location.
6. Report any devices out of service or that no data is available from.
7. If lightning detection system data is available. Was there lightning in the area?

The information available must then be assessed as to the possibility of an event assessment. For the inexperienced analyst assistance by a more experienced person may be required at this point due to complex events or lack of good data or information.

At this point any available waveforms can be reviewed and compared to existing fault signatures in order to enhance the process.

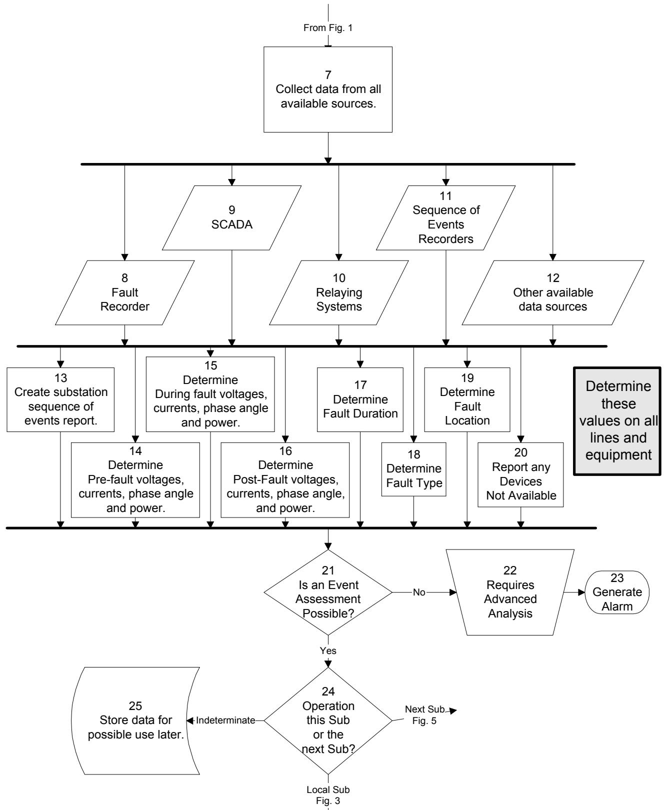


Fig. 2

INFORMATION ANALYSIS

The important point to identify here is if there is enough data to allow an event assessment. Should the inexperienced engineer have problems making this decision any error should be in the conservative, by asking more experienced personnel for their opinion.

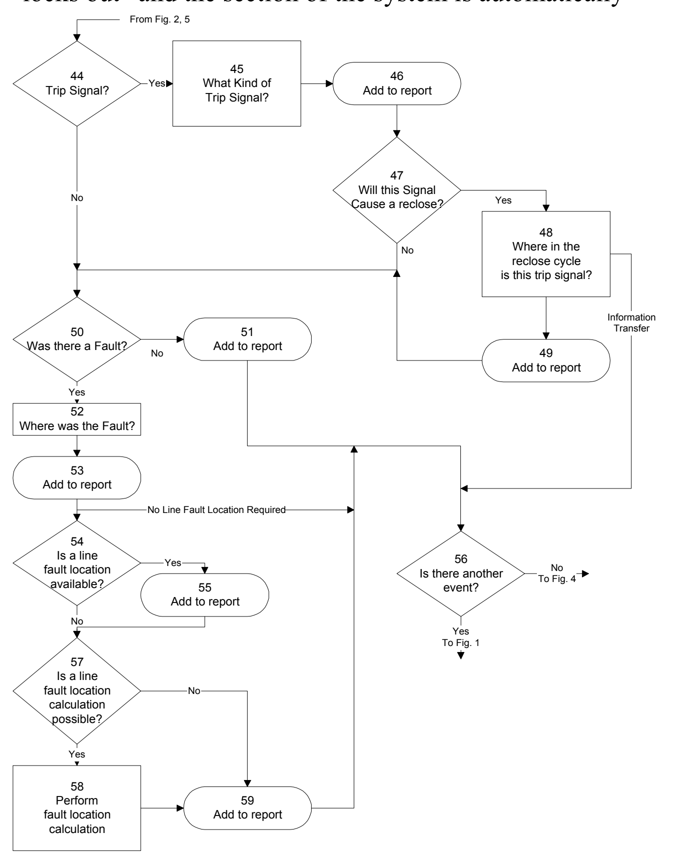
When enough data is available then the analyst should first verify which zone of protection the fault occurred in (i.e. line, bus, bank, etc). Then to collect the information of the parts of the circuit that fed the fault or event. The way this can be determined is by what device initiated the data collection. In the case of a line operation it is suggested that a determination of fault location be made at this time.

Fault locations are provided by the newer relays, if a fault locator is available then it should supply the information, or the fault location may be calculated using the fault magnitude obtained from DFR's or relays.

The information should then be used to determine if the backup protection responded correctly. Also, if the pilot channel equipment worked as required by the scheme.

Now the most important question becomes was a trip signal initiated and by what device. Once it has been determined which device initiated the trip the determination of the status of the automatic reclosing system must be made. If this trip will begin a reclosing cycle then data needs to be collected on the next event. It may be a successful reclose or another trip. It should be noted along the way as which data and information coincides with which event in the reclosing cycle.

This analysis loop needs to continue until the line or device "locks out" and the section of the system is automatically



restored to service (i.e. the line closes and holds).

Fig. 3

INFORMATION TO KNOWLEDGE TRANSFER

We have turned the data available into information to allow analysis, now knowledge is required to know what happened, and when. At this time in the sequence of analysis a report can be generated containing an assessment of the event, a determination of the correctness of what happened, a solution to any problems found, or suggestions for further investigation.

The above information should be transferred to the necessary personnel as quickly as possible not only to return as much of the system as possible to service, but also to insure that damaged equipment or lines are not re-energized. Re-energizing damaged lines and equipment could further damage the system, cause cascading events, cause catastrophic failure of equipment and be very dangerous to the public welfare.

POST EVENT ANALYSIS

There are many other monitors that might be located within a substation and the data they provide can be just as important to a reliable system as the data used during fault event analysis.

A partial list of items that need to be checked against normal operating conditions following a fault event are:

1. Transformer Temperature
2. Transformer Gas Analysis
3. Transformer Oil Level
4. Breaker Opening Time
5. Breaker Opening Pole Agreement
6. Breaker Closing Time
7. Breaker Closing Pole Agreement
8. Breaker Pressure Measurements
9. Power Quality, (Pre and Post Fault)
10. Insulator contamination monitors
11. Lightning detection systems

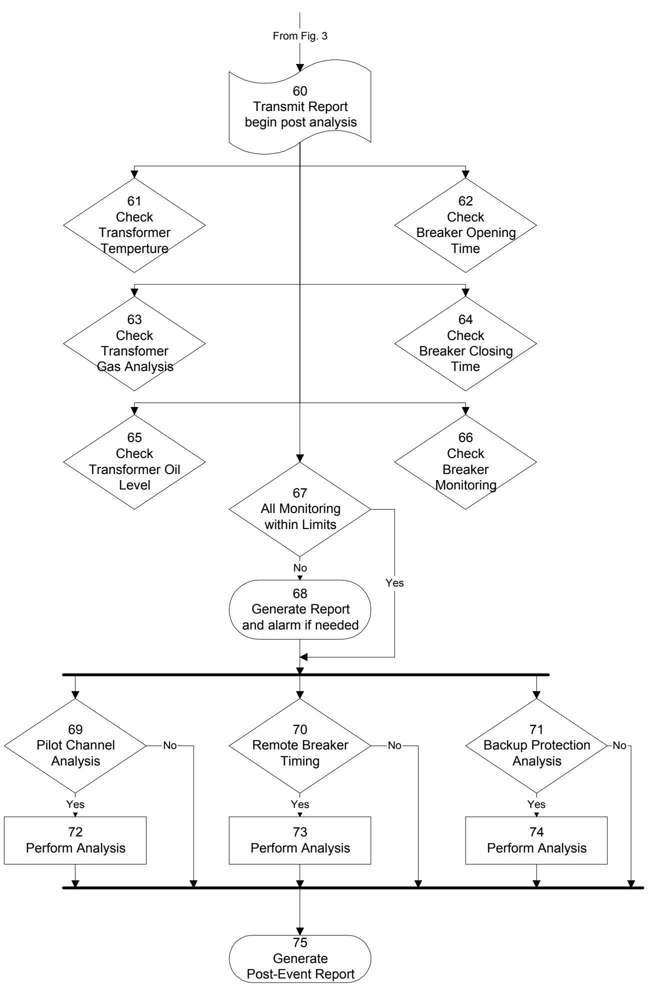


Fig. 4

The above are just examples of the types of information that can be obtained and might prove valuable not only in the post analysis process, but also as indicators of flaws that may later develop into major problems. This information placed in the correct area of responsibility can be used to help drive a right-time maintenance system.

The final analysis that needs to be performed is a detailed look at the protective systems and an attempt to ascertain the correctness of remote devices. Data might be available to determine if the remote end devices have operated correctly and if the remote breaker responded correctly.

A more through investigation of the pilot channel equipment might be performed as to the timing of changes and arrival of signals.

The entire substation backup protection system should also be looked at. Not only the differential protection, and transformer backup protection, but also the secondary line protection (if installed) and the breaker failure relaying. This information is also very valuable in preventing disruptions later.

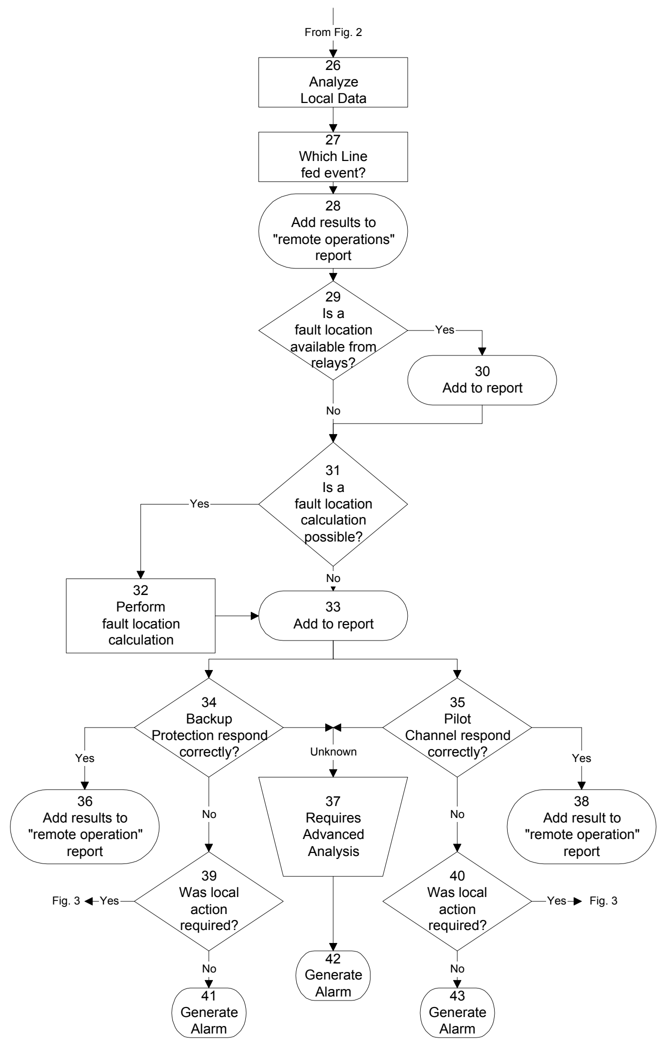


Fig. 5

CONCLUSION

The data within the substation has now been analyzed and information is available to make decisions. This decision-making knowledge can then be turned into action to return all of the equipment to service, repair as necessary, or to modify to ensure no further events.

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APPENDIX

Examples:
The following examples have been included for showing how the flow-chart may be used to begin the analysis process. These examples are not totally inclusive and in no way are to be assumed so

Example 1 (Distribution, Electro-mechanical)

SCADA reports that distribution breaker xxx has tripped. The breaker then recloses and stays.
Therefore, an event occurred.
Things we know:
Overcurrent protection
Electro-mechanical relays (one set of targets for the entire event)
Recloser in service
From decision (1) we can see that there was an event.
From decision (2) we can see that there was at least one reclose.
We then record the line name, substation name, and breaker number of the breaker that operated.
We also record that there was at least one reclose.
From the SCADA master we determine that in fact we had only one reclose shot at 15 seconds. (SCADA)
We check the recloser settings and find that it is indeed set at 15 seconds. (Other)
When the targets are reported operations reports that an instantaneous phase one target was dropped on the distribution relays. We now know that the fault was cleared in the seven to ten cycle range. (Relays and settings data i.e. other)
If in this case we have no other data sources available we then assume that this was a correct operation and continue to the next example.

Example 2: (Distribution, Electro-Mechanical, Multiple recloses)

SCADA reports that distribution breaker xxx has tripped.
Therefore, an event occurred.
Things we know:
Overcurrent protection
Electro-mechanical relays (one set of targets for the entire event)
Recloser in service
From decision (1) we can see that there was an event.
From decision (2) we can see that there was at least one reclose.
We then record the line name, substation name, and breaker number of the breaker that operated.
We also record that there was at least one reclose.
From the SCADA master we determine that in fact we had three reclose shots. The last two being at thirty seconds and forty seconds. We also note that the breaker tripped following the forty second shot. (SCADA)
We check the recloser settings and find that it is set for an instantaneous, thirty second and forty second reclose cycle. (Other)
When the targets are reported operations reports that an instantaneous phase one target and a time ground target were found on the distribution relays.
With the amount of available we know several things as we progress through the flow-chart.

1. We had multiple events.
2. The recloser seems to have worked correctly.
3. The targets both may or may not be for this operation. (Electro-mechanical relay targets not only don’t get reset sometimes, but be aware also that they don’t always drop.)
4. If the distribution personnel require more information, then more data will have to be found. (i.e. waveform data, fault magnitudes, fault duration’s, and/or fault location)

If in this case we have no other data sources available we then assume that this was a correct operation and continue to the next example.

Example 3: (Transmission, Electro-Mechanical)

We are told that SubA to SubB 115kv line has operated.
From decision (1) we can see that there was an event.
We are also told that the line reclosed and held.
From decision (2) we can see that there was at least one reclose.
From SCADA we find that the breakers on each end of the line operated and that both breakers closed and held.
We check the recloser settings and find that the first shot is an instantaneous shot so with no time showing between the trip and close per SCADA we assume that the recloser is correct.
When the targets are reported operations reports that a step distance zone one target was dropped at subA and a step distance zone two target was dropped at subB on the transmission. We now know that the fault was cleared in the seven to ten cycle range from subA and x to x cycles from subB. (Relays and settings data i.e. other)
Everything appears correct and from the targets we know that the fault is located closer to subA. Because the zone one at reach at subA is shorter that the zone two reach at subB. If we were to plot the reaches from the two relays for the targeted elements we would have an overlap, and could supply maintenance personnel with a very rough fault location.

Definition of Flow Chart Blocks

Please refer to associated block number on the included figures.

1. Did Something Happen?

WHAT IS AN EVENT? An event is a relay or switching operation or an inadvertent operation caused by changes in power system parameters measured at the substation. The first thing that must happen is someone must determine if an event occurred. If it is not possible to determine if an event occurred the process moves to "3".
Generally, this process will begin with notification by the operating department that a breaker or protective device has operated. It may also begin with a routine checking of operations or data. As related to the local substation, this process would be initiated by an operation of some device or the automated collection of data by some type of protective or monitoring device.

2. Return to Monitoring

Returns the systems to its normal monitoring state with everything poised to acquire new data should another event occur.

3. Store data for possible use later

Should a determination be made that an event did not occur. Any and all data generated should be stored against the possibility that sometime in the future it might be determined that something did occur and the data would need to be analyzed at that time.

4. Is this a reclose?

A determination should be made at this time if the information being gathered is for the initial event or subsequent events within the reclose cycle.

5. Begin analysis and start reporting process

In the human mind the first analysis begins with the first collection of data. However, if a machine is collecting the data the process must be initialized. The reporting process should start at this point and all data collected and processed should be added to this report in a manner consistent with the policy of the controlling body.
At this time it may only be the collection or logging of the files or data. Notes should be maintained on any information that is not automatically recorded. This would include flags or targets from electro-mechanical devices, human observation, numeric counters, etc.

6. Continue same report and check reclosing cycle

If this is part of the reclose cycle then the data gathered should be continued within the same report. In addition a determination should be made as to the time difference between operations in order to verify the reclosing cycle.

7. Collect data from all available sources

This is a critical step in the overall process. Data should be collected from sources as listed in the following steps.

8. Fault Recorder

The fault recorder can be a very critical piece of equipment for the analysis of events. Since part of what is being analyzed is the protective system is very difficult to rely solely on the protective system to supply the data necessary to assess it's own correct operation. The fault recorder supplies data that is usually sampled at a much higher rate that the protective system. This data then supplies information on not only the protective system, but can also provide data to access the pilot channel equipment, the circuit breakers, the current transformers, the voltage transformers and other associated devices.
The fault recorder can supply data from before the event, during the event and after the event allowing analysis of the entire disturbance. It is critical that the correct information is recorded and the machine is calibrated correctly. Information on what should be recorded can be found in IEEE document 95 TP 107 "Fault and Disturbance Data Requirements for Automated Computer Analysis". This document details exactly the values to be recorded to allow the proper analysis of various different disturbances.
If it can be determined that the recorder is operating properly and is calibrated correctly, and the sensors are properly set. Then even the fact that the fault recorder NOT operating can be a very vital piece of information.

9. SCADA

SCADA data provides data on various automatic and manual events occurring on the electric system. Although the time stamp may not be as accurate as other devices within the substation, the data does provide good information on the correlation of automatic and manual events. The SCADA information can be used to determine switching sequence and sometimes initiating mechanism.

10. Relaying Systems

As stated previously the relaying systems can provide very good information as to what happened and the sequence things happen in. The new technology relays provide much more information that older systems. One must be very knowledgeable on the proper response of these systems, what exactly certain targets mean, and what the fallacies of these

systems are. Care should be taken when evaluating information provided because of these things.
Information from these devices may be used to determine what the initiating protective element was. Using the settings of the device, determination may also be possible on the magnitude, and timing of the event.
As more and more modern relaying is installed the information available grows. However, as the experts leave the knowledge of the older systems also departs and the analysis of older schemes and system may become more complex simply because no one knows how the systems should operate or why a scheme was designed as it was.
It should be stated here that one can define how a system should operate or respond, but defining how as system can mis-operate encompasses an infinite number of answers. So the important thing to remember is knowing how something should work and then determining where in the process it deviated from the norm may provide the clue to what went wrong.

11. Sequence of Events Recorder

A sequence of events is very helpful in the evaluation of exactly what happened within a substation or on a system. Several things should be considered as this is evaluated. The first is the question of time synchronization. Is all the data being considered based on the same time? Is that time synchronization all accurate to the same time base? (I.e. one millisecond) Are all the needed contacts or events being recorded? Can I correlate data from different sources?
In other words, am I able to use data from relays, fault recorders and sequence of event recorders to make one substation sequence of event record?
The information provided by this sequence should also be compared with a known response. It maybe possible during the cut in phase of construction to develop standard sequence of events charts that might be used later for the analysis of problems.

12. Other available data sources

Information from other sources may also prove valuable. First human observation, switching logs, customer reports, all may prove of importance before the entire event may be analyzed. Searching out this information may be time consuming, and troublesome, but very valuable.
Then should it appear that some device did not response as expected. The manufacturers experts may have to be consulted in order to verify exactly how a device would respond to any set of circumstances. Here the data collected would again prove valuable to the manufacturer allowing them to recreate the exact circumstances that the device was subjected to.

13. Create substation sequence of events report

As the analysis process goes on the creation of this substation sequence of events report may be the one thing that provides the clue necessary to solve the problem. Make sure that adding to this part of the report continues through out the entire process.

14. Determine Pre-fault voltages, currents, phase angle and power

These values may be obtained from the fault recorder, the relays, and/or the SCADA system. They may not be of value at all times, but should be utilized when necessary. They will be of most value when testing of the protective systems are involved. It may be critical to the process to know and apply the exact values prior to the event in order to understand why the protective system responded as it did.
Normally, the first of a sequence of occurrences will show the normal voltages and currents that are on the protective devices. However, when or if these currents or voltages are reapplied becomes critical if an abnormality should occur later.

15. Determine during fault voltages, currents, phase angle and power

During fault values are very critical to know, for they can not only be used to evaluate the response of the protective system, but when used in conjunction with the pre-fault values, used to calculate a fault location. Not only are the magnitudes of importance, but the angular relationships are required to properly test the protective systems response to the exact conditions present during the event.
When evaluating the during fault values it maybe important to determine if any harmonics, dc offset, saturation or any other abnormality of the quantities is present as the devices may respond differently if the waveforms are not pure sinusoidal.

16. Determine post-fault voltages, currents, phase angle and power

These values may be of benefit to determine how the entire system reacted to the event. What was the response of generation following the clearing of the event? What was the response of load following the event?
These values, waveshapes and angular relationship will be of great use when determining stability, etc.

17. Determine fault duration

Here there are two different times involved. One is the time the system was subjected to each event. The other is what was the entire duration of all events involved? For example the entire reclosing cycle.
It must be noted here that care should be taken in the evaluation of the fault duration. Each phase should be evaluated. Information on the circuit breaker operation and other devices response may be evaluated at this time.
Circuit breaker re-strikes and fault re-ignition, or just two of the various occurrences that may be evaluated at this time.

18. Determine fault type

Here the interest lies in what phases were involved in each part of the event. How did the event evolve? Did the fault evolve during a single event, or did the fault change with each occurrence? A careful evaluation may determine that a different protective device or a different element should have reacted at different time during each occurrence or differently on different occurences.

19. Determine fault location

Fault location has two parts. The first is an operating issue, in where should the system be isolated to prevent further occurrences. The other is a maintenance issue, as to what equipment needs checking or repaired in order to return it to service. A fault location may have to be calculated by some means if it is out on a line. But it may be also be determined by which protective system operated. As evidenced in the case of bus or bank differentials.
There are many protective devices that provide a fault location calculation. These are performed using many different formulas. Calculations may also be performed after the fact.

As was noted earlier, during fault values are of prime importance when calculating fault location, however, pre-fault values may be required by some formulas.

20. Report any devices not available

In this situation it is important to know any devices that are out of service to know what data will not be available or what things were prevented from happening.

This should include both protective devices, monitoring devices, circuit breakers, switches that are abnormal, lines that have been taken out of service, and pilot channel equipment, etc.

21. Is an event assessment possible?

The first decision that should be made at this point is, do I now have enough data available that an event assessment is possible. If so the process can continue. If not the search for data should continue until the answer to the question is yes. Or, the data should be given to someone else. (box 22)

22. Requires advanced analysis

Here is where the local resident expert is expected to provide expertise in assisting in the analysis of this problem. They also may provide alternate locations from which other information may be obtained.

Here this expert will draw on knowledge of the system as a whole and of passed experiences or problems to make assumptions.

23. Generate Alarm

At this time the generation of the alarm would involve be passing the data available on to someone else for advanced analysis. It might also mean alerting operating or maintenance personnel of critical problems that have been determined from the initial analysis.

24. Operation this sub or next sub?

At this point from the data available the question that must be answered is was the operation inside this sub or the next sub? Did something here initiate any action or did the initiate come from outside?

Following this determination a clear path as to the type of analysis required will be evident.

25. Store data for possible use later

If it can not be determined where the operation occurred, then the data should be stored for future analysis and/or others should be notified that need to be involved in the process. (i.e. the expert of box 22)

26. Analyze local data

The process that follows from here until box 43 involves the analysis of data in the attempt to evaluate events that occur outside of the local substation.

27. Which line fed event?

Data should be analyzed to determine which of the lines out of the local substation fed any event that occurred on the system. The most likely line will be the one with the most current flow. However, knowledge of the system is critical in order to make the correct assumptions.

It can not be emphasized enough that the most important characteristic of the analyst should be a through knowledge of the electric system involved and the protective schemes used.

28. Add results to "remote operations" report

The information resulting from the evaluation of box 27 should be included on the report at this point.

29. Is a fault location available from relays?

If the relaying systems in the local substation are capable of providing fault location there may be a possibility of getting a fault location estimate from them. Even though the fault or event is beyond the next bus some relaying systems may provide an approximate distance to fault.

30. Add to report

If a relay did provide an estimated fault location in file format that can be included in the report it should be added at this time.

31. Is a fault location calculation possible?

Does your company have a way of calculating a fault location on a remote fault? If the answer is no continue on and possibly investigate that possibility for the future.

32. Perform fault location calculation

If so that fault calculation should be performed either automatically or manually at this time. Depending on the electric system any generators, transformers, or lines out of service at the time of the event may need to be considered during the performance of a fault calculation.

33. Add to report

When the fault location calculation is completed or it is determined that it is not possible that information should be reported.

34. Did backup protection respond correctly?

There are ways that the backup protection may be evaluated. That evaluation should be performed at this time. Relays response for zone 3 action. Relays events generated for the event. These are several of the items that might need checking.

35. Did pilot channel respond correctly?

Did the sub receive a carrier-blocking signal? Did it properly receive any other pilot channel indications? Here knowledge of installed protective systems is critical in order to evaluate this response.

36. Add result to "remote operation" report

Add any information found to the report under the heading of remote operation. This may also generate information that may be used in the evaluation of the event in the substation that was involved.

37. Requires advanced analysis

Advance analysis may be required here because of the knowledge level of the person performing the analysis. If so the expert consulted in 22 should be used or various other equipment experts consulted if a determination has been made as the where or what the problems is.

38. Add result to "remote operation" report

Add any information found to the report under the heading of remote operation.

39. Was local action required (backup protection)?

At this time it may prove beneficial to determine if any local action was required that did not occur. If so a branch is necessary to evaluate what should have happened.

40. Was local action required (pilot channel equipment)?

At this time it may prove beneficial to determine if any local action was required that did not occur. If so a branch is necessary to evaluate what should have happened.

41. Generate Alarm

An alarm should be generated if a correct response was not provided. Maintenance personnel should be informed as to what possible action is required to correct any problems found.

42. Generate Alarm

An alarm should be generated if a correct response was not provided. Maintenance personnel should be informed as to what possible action is required to correct any problems found.

43. Generate Alarm

An alarm should be generated if a correct response was not provided. Maintenance personnel should be informed as to what possible action is required to correct any problems found.

44. Trip signal

From here to step 59 the process will be evaluating any local action taken or required. Examination of the data available should allow the analyst to quickly determine if a trip signal was present. Did a device operate? A circuit breaker? Are there targets?

45. What kind of trip signal?

What type of trip signal generated will drive how extensive the analysis is. At this point a determination needs to be made if a lockout relay operated. Did a breaker failure condition occur? Did the trip require the isolation of a bus or a bank? Did the pilot channel equipment call for the trip? Did the lack of a pilot channel signal cause the trip?

The evaluation of the type of trip present, or the lack there of, is a very important part in the total analysis package.

46. Add to report

With the addition of this piece of information to the report, the analyst should evaluate the need to report the type of event to the operating personnel in order to speed restoration of service or to prohibit any further damage or stress on the electric system.

47. Will this signal cause a reclose?

The alternative to this question is will this trip prohibit further reclosing?

48. Where in the reclose cycle is this trip signal?

If a reclose is allowed by this type trip, then a determination of where in the reclosing cycle this trip event is needs to be made at this time. This information should be used in box 56 for determining if another event may be expected. This information should also be used to determine the correct timing of the reclosing.

49. Add to report

All information should be reported again.

50. Was there a fault?

If no local trip signal was generated in step 44, a careful determination needs to be made at this point as to the location of the fault. Here, if possible, data should be gathered from the system as a whole as to the events going on. Since we only have information from our local substation. Evaluation should take place as to current flows, etc. to attempt to determine the general location of the fault.

The events occurring in the local substation may be caused by the inaction or mis-operation of devices in a remote substation or the inability of other equipment to function properly. Inaction by the protective devices within a substation may also be caused by incorrect setting on protective devices or associated equipment.

51. Add to report

All information should be reported again.

52. Where was the fault?

Following the examination of the currents, voltages and trip signals previously, now a determination has to be made as to where the fault might be located. If it appears that the fault is out one of the connected lines, then following the adding of the information to the report we should continue the process of locating it. If it appears that all currents are coming into our sub, the process should continue at step 56.

53. Add to report

All information should be reported again.

54. Is a line fault location available?

If there was a fault, and no trip signal was generated and it appears that fault was out a connected line, the relays should be checked for fault location information. If no fault location information is available proceed to step 57.

55. Add to report

All information should be reported again.

56. Is there another event?

From the information gained in steps 47 and 48 we should be able to determine if we expect another event to be part of the disturbance we are evaluating.

57. Is a line fault location calculation possible?

If enough data is available and we have the capability of performing a fault location calculation. That calculation should be performed now.

58. Perform fault location calculation

If enough data is available and we have the capability of performing a fault location calculation. That calculation should be performed now.

59. Add to report

All information should be reported again.

60. Transmit report begin post analysis

If we have followed the process correctly and arrived at this point it is time to generate the report and transmit it to the appropriate people. Making sure we have added time, date, location, equipment involved, etc.

It is also appropriate to begin the post analysis phase of our event evaluation. The information needed here may also have been used in the analysis of the event. But it may be information that comes in via a different path and gets to the analyst at some later date or time.

This information may be provided and/or evaluated by monitors connected to the associated devices. Or it may be something that has to be derived from other data.

61. Check transformer temperature

Here an evaluation of the transformer temperature before, during and following the event is required. This should determine if the transformer might have been damaged during the event.

62. Check breaker opening time

The events generated by relays can be used here to determine the correctness of the circuit breaker opening. However, digital fault recorder records give more accuracy due to their higher sampling rates and the fact that normally they record for longer periods of time. Evaluation of the time at which the trip is applied until all main contacts are open gives a good check on the breaker operation. The time differential of the main contacts opening provides an indication of pole agreement. Knowledge of the type circuit breaker and its' operating characteristics is a requirement for determining correctness.

63. Check transformer gas analysis

Installed transformer gas analysis devices or a manual gas sample provides a good indication of transformer health. If an automatic device is installed checking the values for several hours following an event can provide a better indication of how the transformer reacted to the events occurrence.

64. Check breaker closing time

The circuit breaker closing timing can be checked in the same manner as described in step 62 for check circuit breaker opening time.

65. Check transformer oil level

Evaluation of transformer oil level before, during and after an event can also be an indication of transformer health as described in step 63 for gas analysis.

66. Check breaker monitoring

Circuit breaker monitoring devices may provide the timing analysis of steps 62 and 64. They may also provide I^2T, contact wear, and other things associated with circuit breakers

67. All monitoring within limits?

After checking all equipment monitoring within the substation following an event, a decision should be made as to the health of all installed equipment.

68. Generate report and alarm if needed

At this point any monitoring that is varying near or outside normal limits should generate a report for maintenance personnel. Should the values be outside acceptable limits an alarm to the maintenance personnel should be generated as quickly as possible.

69. Pilot channel analysis?

If pilot channel equipment is installed within the substation a full analysis of its' performance should be performed in step 72. If not, no action is required.

70. Remote breaker timing?

If devices have recorded enough information on remote breaker operations a full analysis of its' performance should be performed in step 73. If not, no action is required.

71. Backup protection analysis?

If backup protection systems are is installed within the substation a full analysis of its' performance should be performed in step 74. If not, no action is required.

72. Perform analysis

At this time, if possible, from the data recorded, analysis of all pilot channel equipment should be performed. Signal levels before, during and after the event. Transfer trip signals moving from guard to trip frequencies, the performance of any required communications between this sub and other subs. (i.e. pilot wire, etc.) The timing involved in the pickup and drop out of the signals should also be considered.

73. Perform analysis

As with the checking of local circuit breakers the pole opening and closing of remote circuit breaker may also be checked. There may be a possibility that the timing of the remote protective system might be guessed at by the location of the breaker trip in relation to the fault inception.

74. Perform analysis

As stated earlier backup protective system may also be checked if enough information is available. The pickup of breaker failure initiate contacts the pickup of backup elements in microprocessor relays, etc. all may be checked if the necessary monitoring has been installed.

75. Generate post-event report

This report should be generated only if a problem is detected during the post event analysis.